STUDY ON THE EFFECT OF SRA ON PLASTIC & AUTOGENEOUS SHRINKAGE WITH AND WITHOUT SUPPLEMENTERY CEMENTITIOUS MATERIALS – A REVIEW

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Abstract - *Shrinkage is having considerable importance while dealing with structure durability. It is a complex process which involves a lot of overlapping factors. A lessening in the volume of concrete during the hydration and drying of cement is commonly referred as shrinkage. Early age shrinkage leads to cracking at early ages when the internal tensile stresses exceed its tensile strength. This may result in the premature damage of concrete structures. An accurate estimation of the magnitude of effective shrinkage strains is required to mitigate the risk of such cracking, ensure durability, to reduce the cost of maintenance etc. This paper discusses about shrinkage, its types, influence of shrinkage reducing admixture and supplementary cementitious materials on shrinkage of concrete.*

***Key Words*: Autogeneous Shrinkage, Plastic Shrinkage, Shrinkage Reducing Admixture**

1. INTRODUCTION

One of the most used man-made materials is concrete. As per the study conducted, based on cement production in 2014, its production ranges from 35 to 53 billion tons. Compared with all other building materials its production is twice. In light of its high compressive quality, toughness, generally minimal effort and probability to shape it into any structure it has gotten irreplaceable in our cutting edge society.

Concrete brings enormous ecological footprint. Cement production results in CO_2 emission approximately 5% to 7%. $CaCO_3$ is converted into calcium oxide (CaO) by releasing CO_2 during the burning of limestone. It was assessed that for each ton of concrete give rise to approximately 1 ton CO_2 is emitted in to the atmosphere. Disposal of concrete also contributes large problems. This issue can be comprehended to some reach out by the expansion of valuable cementitious materials, for example, flyash, ground granulated furnace slag and silica fume by reducing the needed amount of Portland cement [Arn Mignon et al.2017, Aboobackar Sidheeq M S et al, 2019].

One of the significant issues in structural building, particularly all through the last 20 to 30 years is the durability of concrete. Capacity of concrete to survive chemical exploitations, changes under the action or influence of weather and abrasion while keeping up the ideal building properties is called as durability. Because of different time-sensitive happenings such as creep, shrinkage, freeze/thawing, action of aggressive agents and alkali-silica actions quality of concrete declines after some time bringing in cracking. Cracks in concrete give a pathway for the ingress of hurtful particles dissolved in liquids and gasses, which may endangers the durability of concrete [Arn Mignon et al. 2017]. On studying the effect of temperature on fluidity, water demand, setting time of cement with and without superplasticizer by Elson John et al. it was seen that with the expansion in temperature water demand increases and viscosity of cement paste decreases. Also at lower dosages of superplasticizer, fluidity decreases with the rise in temperature; however, at higher dosages it increases. Premature loss of workability was also observed due to poor cement-admixture compatibility which in turn affects the quality of concrete and construction schedules [L. Thomas et al. 2017]. So as to keep up the ideal building properties appropriate upkeep, repair or even destruction will get fundamental.

2. SHRINKAGE OF CONCRETE

One of the most detrimental properties of concrete is its changes in volume. Various aspects of volume changes were described using the term shrinkage which affects the long term strength and durability. Shrinkage of concrete causes cracks in concrete, therefore it cannot be avoided. Shrinkage is classified into: Plastic Shrinkage, Drying Shrinkage, Autogeneous Shrinkage, Carbonation Shrinkage, and Thermal Shrinkage. Two discrete stages at which shrinkage occurs in concrete are early and later ages. First 24 hours after casting is defined as the early stage. In this stage setting and hardening of concrete starts. 24 hours and above is advised as later ages. Drying shrinkage, autogenous shrinkage, thermal shrinkage occurs in both stages but with different mechanisms [Erika E Holt, 2004]. Mohammed seddik et al. suggests that shrinkage should be measured either through a conservative approach or through a progressive approach. Measurement of shrinkage from the end of plastic phase is the conservative approach. Shrinkage measurement from the maximum rate of deformation is the progressive approach. Length comparator can be used for measuring shrinkage of concrete [Miguel José Oliveira et al. 2014]. Binder-to-sand ratio in the ambit of 1–1.1 was found to be optimum for reducing shrinkage [T. Xie et al. 2018]. Hans Beushausen et al inferred that reduction in the rate of shrinkage development, increase in elastic modulus and tensile strength leading to an increase in the age and net age at cracking was observed with continued or better curing.

2.1 PLASTIC SHRINKAGE OF CONCRETE

Difference in bleeding and water evaporation rates causes the development of capillary stresses at the exposed surfaces of concrete. This is considered as the main drivers of plastic shrinkage. Plastic shrinkage of concrete can also be due to plastic settlements. Plastic shrinkage cracks are mainly due to physical mechanisms, chemical occurrences have slight effects on the early-age shrinkage of concrete [Faris Matalkah et al. 2018]. The ASTMC1579 mould was used for plastic shrinkage study. During the experiment, time of occurrence of first crack was noted. Above the central riser a fine hairline crack running all over the breadth of slab was observed in plain concrete. Further drying results in the widening of this cracks. Occurrence of first crack in concrete specimens reinforced with fibres took a comparatively longer time (more than 7 h). Crack above the central stress riser run nearly straight throughout the width of specimen in plain concrete. The crack was somewhat short, discontinuous and took an indirect path around aggregates or along fibres in fibre concrete. Weak spots for plastic shrinkage crack formation occur as a result of plastic settlement cracking due to differential settlement. Distinct behaviours of pure plastic settlement and pure plastic shrinkage cracking may alter significantly if both plastic settlement and plastic shrinkage cracking exists. Internal cracks and several external cracks are commonly found due to pure plastic settlement cracking. Rapid solitary cracking through the slap thickness was found due to pure plastic shrinkage [Riaan Combrinch et al. 2018]. It was found that addition of fibre reduces plastic shrinkage cracks significantly by 50–99% in comparison with normal concrete. [A. Sukumar et al. 2014]. Crack reduction is more effective with the accession of hybrid cracks compared to individual steel fibres. Steel- polyester fibre combinations results in crack reduction of about 99% compared with that of plain concrete [A. Sivakumar et al. 2007]. José Mora-Ruacho et al. observed that until the surface water evaporates no shrinkage was observed. Crack initiates when the capillary stress peaks with shrinkage strain. Plastic shrinkage occurs before and during setting, when the evaporation rate is moderate (drying at 20 °C and a relative humidity of 50%). Plastic shrinkage happens only in the plastic state, prior setting; when the degree of evaporation rate is high.It was also found that all differences in shrinkage due to the variation in mixture design vanish as the evaporation rate becomes high [Philippe Turcry et al.2006]. Ghourchian et al. observed that plastic shrinkage cracking growths with the fall in clinker content and for cements with same clinker content risk of plastic shrinkage cracking declines with the increase in cement fineness. Various phases of plastic shrinkage can be identified by monitoring the movements uninterruptedly during drying [Philippe Turcry et al.2006]. Mechanism of plastic shrinkage failure is that with the evaporation of surface water a meniscus is formed in the surface pores and the capillary pressure rises. Stiffness increases dramatically with this capillary pressure which further leads to the increase in stresses. Crack initiates when these stresses exceed the failure limit [Sadegh Ghourchian et al. 2019].

J. Kurian et al. detected that incorporation of SCM a delays the time of occurrence of hairline, centre line initial and full-length crack. He also concluded that occurrence of centre line initial crack was fast and its propagation is slow for mixes with GGBS alone also, mixes with fly ash alone shows faster crack propagation and delayed occurrence of initial centre line crack. Use of appropriate mix designs, additions of low volume fibers, use of mineral admixtures was found to reduce plastic shrinkage cracking. Bleeding of concrete and degree of evaporation can be well-adjusted with the practice of using wind breakers, temperature control of both ingredients and environment and appropriate curing so that plastic shrinkage cracking can be minimized. [M. Kayondo et al.2019].

2.2 AUTOGENOUS SHRINKAGE OF CONCRETE

Volume change due to loss or ingress of substances, temperature variation, and application of an external force and restraint can be considered as autogenous shrinkage. It is also referred to as self-desiccation shrinkage. With the increase of silica fume content autogenous shrinkage increases [Linmei Wu et al. 2017].

Measurement of autogenous shrinkage is broadly divided into direct methods and indirect methods. Direct methods include volumetric and linear measurement. For small cement paste or mortar samples buoyancy method is commonly used. Both chemical and autogenous drying shrinkage can be determined by means of corrugated tube method. This method is considered as the best method for autogenous shrinkage measurement as it is less dependent on the environment and can be measured immediately after casting. Indirect methods include contact methods and non-contact methods. By embedding sensors in samples correctness of autogenous shrinkage measurement using contact method can be increased. Autogenous shrinkage can also be determined by measuring porosity and change in relative humidity [Zhangli Hu et al. 2014]. Length change of prisms casted in ASTM C157 based mould can be used for computing autogenous and drying shrinkage of the specimen. On analysing the autogenous shrinkage, tensile strength, and crack area of cement paste with SCMs by Yue Li et al. a decrease in autogenous shrinkage for concrete containing flyash and an increase in autogenous shrinkage that with silicafume was observed. As water – binder ratio increases both autogenous shrinkage and crack area of cement paste was found to decrease. Shrinkage and self-induced stress develops at a faster rate at higher temperatures leading greater cracking risk. Higher shrinkage was observed in cement containing BFS after 6 days than Portland concretes at all temperatures [Pietro Lura et al. 2001].

E. Holt et.al suggests that with the use slower hydrating cements, cement with lower C3A and C3S content, by maximising the aggregate content and by avoiding the delay in setting time autogenous shrinkage occurring at early ages can be minimized consecutively.

Reduction in volume due to the evaporation of water upon drying is termed as drying shrinkage. Only after 7 days drying shrinkage is measured. B. Rongbing et al. showed that free drying shrinkage can be lowered to 30-40% with 2% dosage of SRA in specimens made with mortar and concrete at 60 days.

Magnitude of carbonation shrinkage is very small and has an accumulated effect. Reaction of cement paste in hardened concrete with CO_2 and moisture in air causes carbonation [Erika E Holt (2004)]. Dissolution of portlandite and its interaction with dissolved carbon dioxide is often used to explain carbonation shrinkage. In comparison with the reference mortar weight loss is accelerated in carbonated mortar. Slight reduction in the final amplitude of the shrinkage was observed with prolonged curing [Othman et al. 2012].

Volumetric changes in concrete due to temperature fluctuations are referred as thermal shrinkage. Early age thermal shrinkage causes cracking in the first day after casting. Due to the action of variable, diurnal and seasonal temperature the cracks thus formed grows up after the end of concrete hardening. Such cracks are usually found in structures such as retaining walls, bridge abutments, walls of liquid storage etc. that needs strict tightness. Curing methods, technology adopted, concrete mix composition and structure dimensions are some of the factors that influence the extent of early age thermal shrinkage loads [Barbara Klemczak et al. 2019].

Shrinkage resulting as a result of hydration of cement is known as chemical shrinkage. Extents of chemical shrinkage rely on cement chemistry and amount of cement hydration. It was empiric that cement with higher C_3A + C_4AF shows higher chemical shrinkage [Wanchai Yodsudjai et al. 2013]. Internal tensile stresses were developed within the cement matrix due to the capillary effects as a result of chemical shrinkage. These stresses are often higher than the breaking stress of the material at early ages leading to the formation of micro cracks [Tarek Merzouki et al. 2013].

3. SUPPLEMENTARY CEMENTITIOUS MATERIALS

Supplementary cementitious materials are constituents that are added to concrete in order to economize concrete by replacing a part of Portland cement. SCMs are added to concrete for modifying the concrete properties through their pozzolanic activity such as its physical properties, initial and final setting time, early rate of gain of strength and heat of hydration and for improving its long-term performance [Banti A. Gedam et al. 2015, Sabarinath R et al. 2016]. Fly ash, slag, silica fume, rice husk ash, metakaoline are SCMs that are commonly used. C_3S, C_2S, and calcium hydroxide are the products formed as a result of the hydration of cement. Among these $CaOH_2$ leaches out and it does not have any cementitious property. The silica in mineral admixture will react with calcium hydroxide under moisture presence to form calcium silicate hydrate gel having high cementitious property and provides strength to concrete [M.K. Abraham et al. 2014]. Ehsan Ghafari et al. concluded the incorporation of FA and GGBS shows similar trend in compressive strength developments. A slight decrease in mechanical properties poorer autogenous shrinkage was also identified in concrete containing flyash. On studying the plastic shrinkage behaviour in concrete containing blended cements by Ghourchian et al. it was concluded that with the decrease in clinker content and higher fineness of blended cements plastic shrinkage cracking susceptibility increases.

Finely divided residue resulting from the combustion of pulverised coal is termed as fly ash. It is the most extensively used pozzolan all over the world. Now a day's use of fly ash became an accepted additive in concrete mainly for producing high strength and high performance concrete [Sarika R et al. 2017]. Due to slowing down of the reduction of internal humidity in the matrix fly ash had an inhabiting influence on autogenous shrinkage. Studies confirm activated fly ash improves both the corrosion resistance (due to increased resistance to chloride ion penetration) and strength of concrete with 20– 30% replacement [V. Saraswathy et al. 2013, I. S. Raj et al. 2019]. Restricted replacement of cement by fly ash was limited up to 30% of total cementitious materials. It was observed that for long-term strength enhancement in concrete higher content of FA at more than 30% is not beneficial [Banti A. Gedam et al. 2015]. 40% and 20% fly ash addition in concrete lowers autogenous shrinkage as low as one tenth of plain specimen's and to half respectively [Linmei Wu et al. 2017]. Jerison Scariah James et al. found out the optimum dosage of flyash as 25%. Cement replacement with fly ash delays the time of occurrence of the hairline, centre line initial and full length crack, but the crack propagation was fast. With the ample usage of such products like flyash exploitation of natural resources and the discharge of greenhouse gases can be reduced [Aneesa et al.2017].

GBFS is another essential material in the form of polished sand like granulated particles. The molten slag was quickly cooled by slaking in water to form GGBFS. Physical properties of concrete like durability, workability increases with the incorporation of using FA and GGBS. The effectiveness of slag mostly depends on the chemical configuration, glass content and quality of grinding. It is likely to substitute about 40–50% of cement by GGBFS without substantial drop in compressive strength of concrete [B. A. Gedam et al. 2015, B. Johny et al. 2014]. Tensile creep of high performance concrete at its early age is increased with the accumulation of fly ash when the loading period was at 1 d and 2 d and an opposite effect was witnessed with those having BFS. If the loading age is beyond 3d not much influence is detected. [Gu. Chunping et al. 2019]. Tarek Merzouki et al. suggested that the risk of cracking in mass concrete is reduced with the reduction of heat of hydration by the introduction of slag. Zhichao Liu et al. suggested that pozzolanic reaction of slag suppresses autogenous shrinkage initially due to its diluting effect and causes an increase in autogenous shrinkage ultimately. M. Shariq et al. observed that concrete containing GGBFS shows higher strains due to creep than plain concrete. Strength development in such concrete is slow which help in the availability of more free water throughout sustained loading period. Addition of GGBFS results the formation of finally dispersed gel which seals the bigger pores on reacting with calcium hydroxide. With this reduction in calcium hydroxide the concrete becomes more stable chemically and chemical resistance increases with the finer pore structure [Roshan Mathew et al.2018]. Replacement of cement with 35% and 40% GGBFS delays the setting time than the control mix whereas GGBS 45% and 50% reduces the setting time significantly with GGBS 50% sets at a faster rate [Sreekumar K K et al. 2016]. A. John et al. saw that as slag content rises porosity of concrete also rises. This may results in the reduction of compressive strength caused due to the weakening of bond between the concrete components.

4. SHRINKAGE-REDUCING ADMIXTURES

Materials that are added either in advance or at the time of mixing other than cement, aggregates and water is called as admixtures. Shrinkage-reducing admixture is a chemical additive that can limit shrinkage. It lowers the possibility of restrained shrinkage cracking [J. Saliba et al. 2011]. It is mentioned that shrinkage reducing agent shows a positive relationship with tensile strength, and a negative correlation with autogenous shrinkage. Cement hydration and strength development reduces considerably in concrete containing SRA at the same time the degree of drying and autogeneous shrinkage is also reduced. Chemical analysis of extracted pore solutions indicates that dissolution of alkalis in the pore fluid gets depressed SRA inclusion. Because of this alkalinity of the pore liquid lowers which in turn results a reduction in cement hydration [Gaurav Sant et al.2010, Farshad Rajabipour et al. 2008]. Not any effect on the attained rate of hydration and a fall in the internal relative humidity was noted for 11 days in cement pastes under sealed condition having organic SRA [Bentza et al. 2001]. Addition of SRA or suitable superplasticizer lowers the evaporation rate, retards the ultimate capillary pressure by improving the menisci in the pores and decreases settlement by reducing surface tension of the mixing water which in turn reduces the cracking due to plastic shrinkage [José Mora-Ruacho et al. 2009, Arya E K et al.2019].

The autogenous shrinkage of mortar declined by 30–40% in the first 60 days, and 20– 30% when duration extended to 90 days with 2% of SRA content. For the high-strength concrete, with the development of capillary pressure on the concave surface, cracking due to shrinkage at the plastic stage was lessened efficiently by shrinkage reducing agents [V. Saraswathy et al. 2013]. Addition of SRA also improves the performance of concrete such as improved corrosion resistance by decreasing chloride-ion penetration rates, improved freeze-thaw performance of the system by decreasing fluid saturation levels performance of the system if a period of initial drying is permitted [Gaurav Sant et al. 2010]. For reducing shrinkage the optimum dose of shrinkage reducing admixture was established as 1% [T. Xie et al. 2018]. Depletion in compressive strength was observed in the presence of SRA whose effect may depend on the length of curing and the amount and type of admixtures used. Flow of concrete also increases with SRA incorporation [Shah et al. 1992, Jerison Scariah James et al. 2019]. By altering the properties of pore solution (by increasing the viscosity and decreasing the surface tension) SRA reduces the moisture and ionic transport in concrete. It was stated that SRA has little influence on the microstructure that develops and in concrete containing SRA chloride penetration was reduced considerably improving the concrete durability [Chunyu Qiao et al. 2017]. Maltese et al. investigated the combined effects of an expanding agent and shrinkage reducing admixture on the hydration of cement. The use of these two materials together helps in obtaining mortars that are less sensitive to drying. On comparison with expanding agents SRA shows better performance in mitigating shrinkage. Ilhami Demir et al. observed that SRA is having an impact on the characteristics of fresh concrete positively. Within the sight of SRA the expansion was found to be higher for specimens cured under water. At early ages SRA is very effective in reducing drying shrinkage nearly to 30% of the one without SRA and at later ages its action becomes gradual. Alexandra Passuello et al. on his investigation noted that incorporation of SRA delays the time of cracking and reduce crack width by 40%. It was also indicated that, addition of macro and micro fibers reduces crack width by 70% and 90% respectively.

5. SUMMARY

Use of shrinkage reducing admixture or a suitable super plasticizer decreases surface tension of mixing water. Shrinkage cracking can be reduced noticeably by lowering the evaporation rate, delaying the capillary pressure. It was stated that until the surface water evaporates there is no shrinkage. Until the capillary stress peaks shrinkage strain increases and the crack initiates. The crack thus formed gets opened up in further evaporation. Studies established that cement with 20– 30% of activated flyash improves both corrosion and strength properties. It was viable to put back about 40–50% of cement by GGBFS without serious reduction in compressive strength. 1% of SRA is considered as the optimal quantity for decreasing the risk of shrinkage.

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